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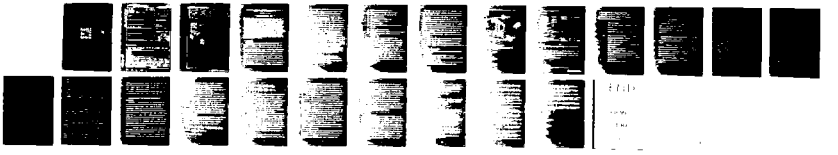

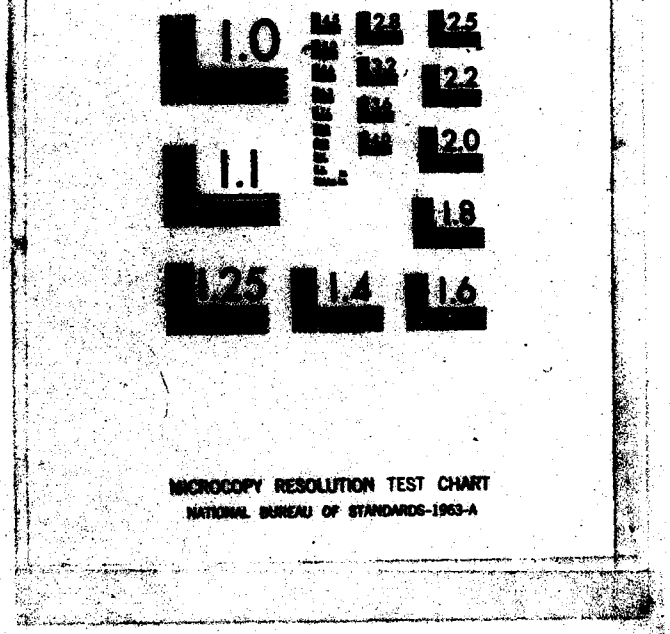
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1. REPORT NUMBER: ETL R-0053	2. GOVT ACCESSION NO.: AD-A135844
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): On Generation, Estimation, Utilization, Availability and Compatibility Aspects of Geodetic and Meteorological Data	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Dr. H. Baussus von Luetzow	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Engineer Topographic Laboratories, Fort Belvoir, VA 22060	12. REPORT DATE: August 1983
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Presented at the Interdisciplinary Symposium "Data Management," International Union of Geodesey and Geophysics (IUGG) XVIII General Assembly, Hamburg, West Germany, 15-27 August 1983

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Generation
Estimation
Utilization
Geodetic
Meteorological

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Following an introduction, the paper discusses in section 2 the collection or generation of final geodetic data from conventional surveys, satellite observations, satellite altimetry, the Global Positioning System , and moving base gravity gradiometers. Section 3 covers data utilization and accuracy aspects including gravity programmed inertial positioning and subterraneous mass detection. Section addresses the usefulness and limitation of the collocation method of physical geodesy. Section 5 is concerned with the computation of classical climatological data. In section 6, meteorological data assimilation is considered. Section 7

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deals with correlated aspects of initial data generation with emphasis on initi wind field determination, parameterized and classical hydrostatic prediction models, non-hydrostatic prediction, computational networks and computer capacit The paper concludes that geodetic and meteorrological data are expected to become increasingly more diversified and voluminous both regionally and globally, that its general availability will be more or less restricted for some time to come, that its quality and quantiy are subject to change and that meteorological generation, accuracy and density have to be considered in conjunction with advanced as well as cost-effective numerical weather prediction models and associated computational efforts.

ON GENERATION, ESTIMATION, UTILIZATION, AVAILABILITY AND COMPATIBILITY ASPECTS OF GEODETIC AND METEOROLOGICAL DATA

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Following an introduction, the paper discusses in section 2 the collection or generation of final geodetic data from conventional surveys, satellite observations, satellite altimetry, the Global Positioning System, and moving base gravity gradiometers. Section 3 covers data utilization and accuracy aspects including gravity programmed inertial positioning and subterraneous mass detection. Section 4 addresses the usefulness and limitation of the collocation method of physical geodesy. Section 5 is concerned with the computation of classical climatological data. In section 6, meteorological data assimilation is considered. Section 7 deals with correlated aspects of numerical data generation with emphasis on initial wind field determination, primitive and classical hydrostatic prediction models, non-hydrostatic problems, computational networks, and computer capacity. The paper concludes that geodetic and meteorological data are expected to become increasingly more available and economical both regionally and globally, that its general availability will be more or less restricted for some time to come, that its quality and quantity are subject to change, and that meteorological data generation, density and density have to be considered in conjunction with numerical as well as cost-effective numerical weather prediction models and geodetic requirements dictate.

1. Introduction.

Fundamental aspects of geodetic data management were addressed at the Symposium on Management of Geodetic Data, Copenhagen, August, 1981, and a number of pertinent articles are published in Bulletin Geodesique, Volume 56. While management of geodetic data is not restricted to gravity measurements and their quantitative identifications, they are playing a fundamental role because of the relative simplicity of their determination, accuracy, frequency density, and geodetic applications, sometimes in combination with satellite and satellite altimetry data. In contrast to essentially static geodetic data and the absence of a critical time constraint as to application, meteorological data for operational numerical weather prediction has to be rapidly acquired and processed for use in dynamic prediction models with

gravity determination. The data base has to be preferably world-
wide, and the output extends to several variables and a number of discrete
points. For this reason, all organizations concerned with operational
oceanography, however, have developed extensive data management systems.
Geodetic and meteorological data management have in common the predominant
participation of governmental or public organizations. There is, however, a much
greater international data exchange in meteorology, dictated by necessity,
while in geodesy military considerations impose certain restrictions at
times. In some cases, proprietary rights are also claimed by private
organizations. As evident from the abstract, this paper is not concerned with
data processing in a narrower technical sense, including consideration of
computer hard- and software management. It emphasizes the influence of
theoretical knowledge on the data generation and identifies some geodetic and
meteorological problems related to data management systems. In the field
of geodesy, it emphasizes in the application of gravity gradiometers and its
impact on geodetic data management. In meteorology, it emphasizes
the need for improved satellite observations and a denser network of
conventional observations and concentrates on the problem of data
assimilation and its intimate relationship with improved dynamic models.
Examples of both of these and other limitations of necessity not
only of technological and economical in nature.

Geodetic and Meteorological Data.

The data required for geodetic purposes consist, under deletion of
auxiliary data for the alignment of geodetic networks and the conventional
treatment of geodetic problems, essentially of:

(1) Satellite Doppler and Related Measurements

(2) Satellite Altimetry Measurements, GEOS 3 and SEASAT

(3) Global Positioning System (GPS) Measurements (New)

(4) Point Gravity Measurements

(5) Elevation Measurements (Topographic Maps)

(6) Astrogeodetic Vertical Deflections

(7) Polar Motion Measurements

(8) Height Anomaly or Geoid Representations (Including Combined Solutions)

(9) Satellite Altimetry Representations

(10) Astrogeodetic - Inertially Determined Gravity Vector Components

(11) Astrogeodetic - Gradiometrically Derived Gravity Vector Components (New)

(12) Satellite - Based Gradiometric Measurements (Future)

The primary data source pertaining to satellites is the National Space [illegible] Data Center, Greenbelt, Maryland (World Data Center - A for Rockets [illegible] also performs data management studies. Gravimetric [illegible] is supplied by the National Geodetic Service Data Center in [illegible], Colorado (World Data Center - A for Solid Earth Geophysics). It is [illegible] with that of the International Gravimetric Bureau, Paris, France, as [illegible] agency of the International Gravity Commission whose data [illegible] has been described by Isaac [1982]. Height anomaly or geoid [illegible] may be obtained from Goddard Space Flight Center, Greenbelt, [illegible] and from the Department of Geodetic Sciences and Surveying, The Ohio [illegible] University, Columbus, Ohio.

While geodetic data generation, except for point measurements, has been greatly facilitated by satellite technology combined with new instrumentation, dense, uniform, and highly accurate regional gravity vector determinations is expected to be performed in the United States after 1987. The projected accuracies of 0.2 arcsec rms and 1 mgal rms in the context of constant elevation networks of considerable size and a grid length of about 5 km will revolutionize physical geodesy in many respects and will ultimately, together with interpolation techniques, simplify many aspects of geodetic data management. Technical details of the Bell gravity gradiometer have been addressed by Metzger and Jamieson [1981], Heller [1981], and Jordan [1982]. For astrogeodetic-inertial and extrageodetic-gradiometric gravity vector determination and a combination thereof, reference is made to Bauswus von Kaufmann [1983].

Meteorological measurements generated for both conventional weather forecasting and for numerical prediction are performed by balloon soundings, polar satellite soundings, and surface pressure measurements in fixed meteorological nets. The measurements are supplemented by data from aircraft and ships.

The polar satellites provide:

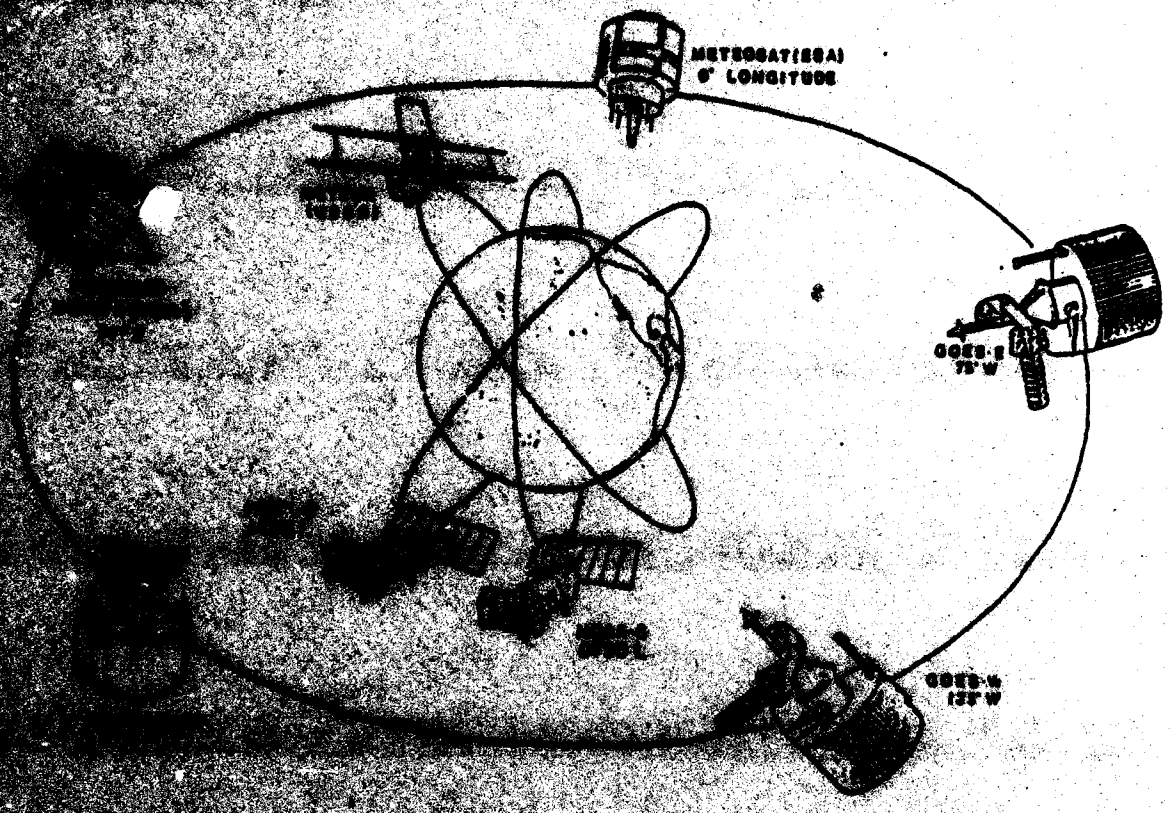
Temperature soundings, sea surface temperatures, snow and ice mapping, cloud retrieving.

Geostationary satellites generate information concerning:

Temperature soundings, cloud motion (wind in about 2 layers), sea surface temperature, precipitation estimates.

A polar orbiting satellite equipped with a scatterometer may also provide information of ocean surface winds according to Pierson [1983].

environmental satellites are depicted in Figure 1 below.



ENVIRONMENTAL SATELLITES, 1982.

[illegible] Polar Environmental Satellite Products List is shown in the [illegible] table.

APRIL 1980

PRODUCT DESCRIPTION	ACCURACY GOALS	SPATIAL RESOLUTION/ GEOGRAPHICAL COVERAGE	SCHEDULE	USERS (Output Media)
[illegible]	SFC-500 mb ± 2.5°K [illegible] ± 2.25°K [illegible] ± 3°K [illegible] mb ± 2.5°K	250 km near the sub-satellite track, increasing with scan angle/ global.	Orbit-by-orbit	NMC (Disk) EDIS (CCT)
[illegible]	± 30% of the true value (or 1 mm whichever is larger)			
[illegible]				
[illegible]	Pressure: ± 50 mb Temperature: ± 2.5°			
[illegible]	± 10% tropical, ± 50% polar			
[illegible]	± 2°K			
[illegible]	± 2%			
[illegible]	In areas of single layer cloud [illegible], ± 2°K [illegible]	500 km near the sub-satellite track, increasing with scan angle global.	Orbit-by-orbit	All customers served by GTS (teletype)
[illegible]	[illegible]			
[illegible]	Pressure ± 50 mb Temperature 2.5°K			
[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	Orbit-by-orbit	GTS (teletype)
[illegible]	[illegible]	[illegible] reduced to [illegible] resolution.	Orbit-by-orbit	British Meteorological Office, Bracknell, U.K. (Telecommunication line)

TABLE

[illegible] SATELLITE PRODUCTS LIST, SOUNDING PRODUCTS

[illegible] Data Services Division of the National Climate Center, Ashville, [illegible] with the operations center of NOAA's National [illegible] Satellite Service, Suitland, Maryland is the United States [illegible] environmental satellite data.

[illegible] Oceanic and Atmospheric Administration.

b. Utilization and Accuracy Aspects of Geodetic Data.

The geodetic data generated by different means enumerated in section 2a will facilitate, sometimes in combination, the establishment and utilization of the following with associated accuracies:

(1) . Improved Geopotential, Non-uniform Accuracy, Equal to or Better than Spherical Harmonics Representation of Degree and Order 360.

. Height Anomaly RMS Error of the Order 1 m.

. Improved Space Vehicle Trajectories and Orbits

(2) . Determination of the First Derivatives of the Geopotential in Regions Covered by Gradiometric Traverses and Cross Traverses, RMS Error 1 mgal or Better.

. Geodetic Azimuth Determination.

. Coordinate Transformation from Local to Global System (Mean Earth Ellipsoid).

. Improved Space Vehicle Trajectories.

. Gravity Programmed Inertial System with Reduction of Horizontal RMS Position Error and Position Error Due to Accelerometer Scale Factors and Gyro Bias Errors, Accuracy of the Order 5.10^{-6} for 60 km Traverse with Initial and Terminal Position Control.

. Improved Geodetic Network Adjustment.

(3) . Rapid GPS Positioning, RMS Error Dependent on Acquisition Time, Reducible to 1 m or Better.

(4) . Subterraneous Mass Detection and Geophysical Prospecting (Oil, Water, Cavities)

The greatest impact on geodetic data management, heretofore strongly concerned with gravity data, has the regional, uniform and accurate determination of gravity vector components by astrogeodetic-gradiometric means in the foreseeable future and the application of suitable interpolation methods addressed in section 4.

4. Usefulness and Limitation of the Collocation Method of Physical Geodesy.

The collocation method of physical geodesy is indispensable for many geodetic applications, its usefulness and limitations characterized by the following:

(1) Interpolation of high accuracy gravity vector components determined by astrogeodetic-gradiometric means in level surface about 500 m above ground and analytical downward continuation to the earth's surface and combination of point gravity anomalies in semi-flat terrain as an integral part of this procedure favored by the uniform distribution of vector observations even in covered regions.

(2) Post-mission adjustment of gradiometric data or optimal gravity vector determination under consideration of initial and terminal vector control data.

5. Climatological Data, Univariate and Multivariate Analysis.

Of immediate interest to climate data management are the Guidelines on Climate Data Organization and Formats, published by the World Meteorological Organization in 1982 (WPC-31). It addresses climate data types, data management principles, management of data bases, and advanced techniques. Associated with the generation of climate data is the establishment of a multivariate statistical interpolation scheme. Such schemes have been discussed by Lorenc [1980] and Gustavsson [1981]. Although climatological means are subtracted from measured or model-generated random variables to be used in the regression estimation, the assumption of homogeneity and isotropy is often made for simplification. Significant in this respect is that the statistical estimation corresponds to the generation of meteorological variables by a simpler model. For the same reason, means, variances and covariances are subject to variations, i.e., do not behave in accordance with an ergodic generation process. In the context of the use of climatological data for estimation purposes the following should be noted:

(1) Stationary statistics involving first and second order moments compatible with an ergodic generation process is applied for the estimation using variables generated by a non-stationary process.

(2) Winds utilised for interpolation and extrapolation of geopotentials are associated with a geostrophic estimation structure and tend to cause imbalances in multivariate analysis, ascertained by Williamson, Daley and Schlatter [1981].

(3) Univariate geopotential estimation does not appear to introduce significant errors if the data points are not widely separated.

(4) For improved univariate estimation, winds require a decomposition in non-divergent and divergent components.

(5) The utilization of measured winds for the estimation of geopotentials should preferably be accomplished in the context of 4-dimensional data assimilation, by univariate analysis, and employment of an improved balance equation addressed in section 7. The ultimate estimation of the geopotential would then be a weighted univariate solution.

(6) The existence of measurement errors and correlated noise can be considered in univariate and multivariate estimation.

6. Meteorological Data Assimilation.

An overview of meteorological data assimilation has been presented by Morel [1981] under inclusion of grid point analysis by multivariate techniques, dynamics of adjustment, normal mode initialization, and 4-dimensional data assimilation. He emphasizes the development of filtering techniques and the consideration of artificial damping pertaining to the generation of meteorological noise during dynamic prediction because of the generation of divergent winds and stated that the mathematical basis for understanding the continous or discontinuous adjustment process involved in 4-dimensional data assimilation is not well established as yet.

Bengtsson, Kanamitsu, Kallberg, and Uppala [1982] discuss the FGGE[2] 4-dimensional data assimilation at ECMWF.[3] The respective scheme is evident from figure 2 below.

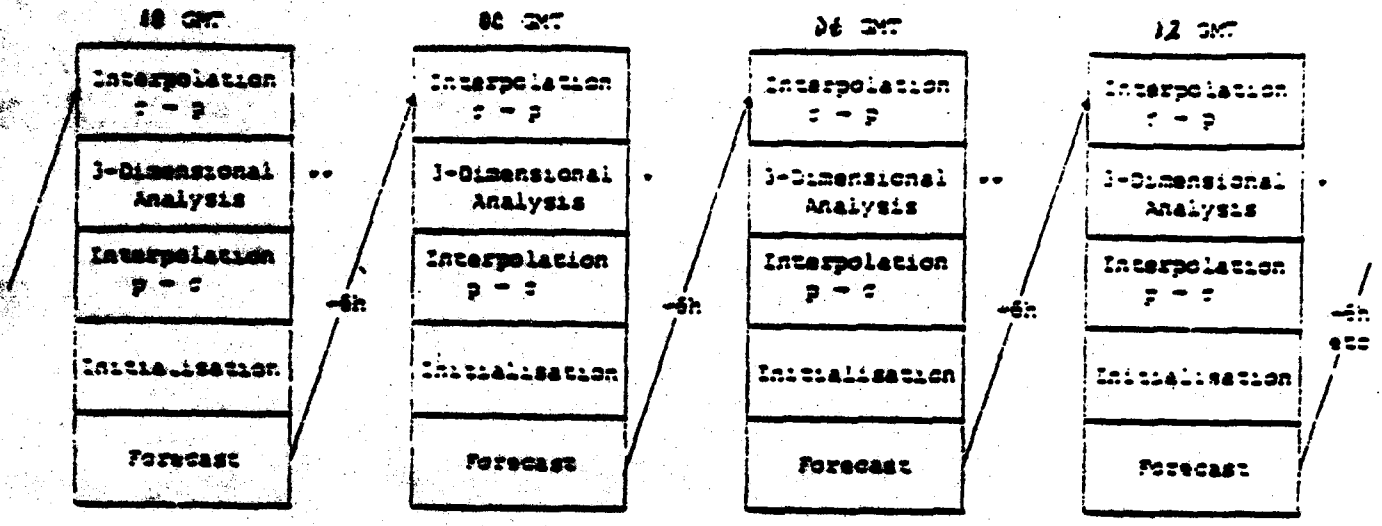


FIGURE 2

The different stages in 4-dimensional data-assimilation at ECMWF (*archived through the whole FGGE year, **archived during the Synopses).

In this scheme, the scalar field variables at a specific time are estimated from their values generated from fields established 6 hours prior to time t_0. This approach presupposes the existence of errors pertaining to the generated and observed fields and their covariances and requires a considerable empirical effort. Nonlinear mode initialization was applied for the

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[2]FGGE: First GARP Global Experiment (GARP: Global Atmospheric Research Project).

[3]ECMWF: European Center for Medium Range Forecasts (Reading, United Kingdom)

computation of quasi-balanced wind and mass fields. The significance is that this approach does not only lead to reduced scalar field errors at time t_o but also to a partial influence of the respective observed fields. For this reason, accurate initialization is important.

The global data assimilation system at the National Meteorological Center has been described by Ward, Kistler, Tracton and Gordon [1981].

7. Initialization, Dynamic Model Improvement, Predictability and Compatibility.

Initialization for determination of the wind field from the mass field under an ever limited consideration of diabatic processes and dynamic model improvement and correlated computer capacity impose data management considerations. Although they ceteris paribus increase predictability, progress herein has to be compatible with the generation of denser and more accurate data primarily by satellites and a greater number of surface pressure sensors, particularly in oceanic areas. A marginal utility analysis would further have to assign weights to short and long range forecasts under consideration of the spectrum of applications. There are already implications that relatively accurate and correspondingly expensive long range predictions for non-military purposes should be centralized in the future. Of specific interest here are the following topics.

(1) Normal Mode Initialization (NMI): Nonlinear NMI along the lines of Williamson and Temperton [1980] is the presently preferred and practiced method to derive mutually balanced mass and wind fields. As shown by Phillips [1982], multivariate optimum interpolation analysis is consistent with NMI if the model-generated first guess data contain only slow modes with correspond-

[illegible] wind observations are used. As indicated in [illegible] data assimilation and the univariate [illegible] at grid points from computed and sufficiently [illegible] with the existence of higher modes and the [illegible] method.

[illegible] of NMI and the Classical Balance Equations: Leith [illegible] of these methods. The truncated balance [illegible] function ψ and the geopotential φ has been [illegible] in his study of elliptic regions in balanced [illegible] which he postulates the need for a [illegible] The inadequacy of NMI and [illegible] has further been established by [illegible] equation and the omega equation [illegible] (1980) [illegible] in a mesoscale numerical [illegible]

[illegible] Equations: These are obtained [illegible] of the second order total time [illegible] in the (x,y,p,t)-system. In [illegible] equation

$$[illegible] \quad (1)$$

[illegible]

$$\left(\frac{\partial}{\partial x}\frac{\partial^2\phi}{\partial x\partial p} + \frac{\partial}{\partial y}\frac{\partial^2\phi}{\partial y\partial p}\right) +$$

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)\frac{\partial^2\phi}{\partial x\partial y} + \frac{\partial^2}{\partial x^2}\frac{\partial^2\phi}{\partial y^2} + \beta\left(\frac{\partial\phi}{\partial x} - 2\pi\right) \qquad (2)$$

In equations (1) and (2) the symbol ~ indicating a filtered variable has been [illegible] actual p-data are employed for initialization. Equation (2) [illegible] to the thermodynamic equation with 3 ellipticity [illegible] a new hydrostatic criterion. The new diagnostic equations [illegible] to the classical balance equation, particularly under [illegible]. They were derived by Sommerm von Lantzow [illegible] as a higher version including non-hydrostatic [illegible] (1979). As is well known, the solution of the [illegible] represents a mathematical effort.

(2) Prognostic equations: The vorticity equation, [illegible] the continuity equation, the diagnostic equation (1), [illegible] equation comprise a hydrostatic signal generation [illegible] to superposition or ellipsis, respectively, and which para- [illegible] problems. Latent influences initially considered to the extent [illegible] diagnostic equations are only subject to small subgrid scale [illegible]. The model generation possess but a definite prognostic capability [illegible] of the equations, the characterized success of spectral dynamic [illegible] a complicated system of equation terms, and shortcomings of the [illegible] numerical system.

(3) Complicated Hydrostatic Prediction (Primitive Equations): The [illegible] system explicitly incorporate convection down to the

[illegible] requiring adjustment schemes, and thus cannot not fully [illegible] with the continuity equation for water vapor. Prognostically, this [illegible] has an increasingly degrading effect, also with respect to the [illegible] of radiation which has not been well accomplished yet at the [illegible] Meteorological Center as reported by Facey, Gerrity and Sela [1981].

(6) Nonhydrostatic Prediction: The use of the prognostic equation for the vertical velocity component is generally prohibited because of [illegible] in the initial fields, the lack of time-varying boundary conditions at the bottom and the top of the atmosphere, and the computational effort required. For a limited area, for the purpose of research, and with [illegible] considerations, Tapp and White [1976] have considered a non-hydrostatic [illegible] model. Leaving the structure of the continuity equation in the [illegible]-system invariant, Kasahara von Luetzow [1971] derived a higher order [illegible] equation for the vertical velocity component, modified in 1980. The [illegible] system, free of internal sound waves, is compatible with a [illegible] grid length down to about 10 km and allows for an essentially full [illegible] of the continuity equation for water vapor. The system simultaneously allows for more vertical levels. As a consequence of computational [illegible] densification, it requires an enlarged computer capacity. In [illegible] with findings by Gordon and Stern [1982], the spectral method is expected to be less suitable in this system, tantamount to the requirement of [illegible] order difference schemes.

(7) Predictability and Compatibility Aspects: Sophisticated models are the necessary prerequisite for long range weather prediction under full [illegible] of the geopotential, humidity and cloud observations, and [illegible] and derived equatorial winds. However, these models cannot

[illegible] for the lack of dense and accurate data. From the standpoint of [illegible], a grid length of 100 km appears to be fully adequate. At the [illegible] grid length must be relaxed. In view of the availability of effective [illegible], in particular equation 1 and the associated omega [illegible], the initial data problem is the most crucial, calling for more and [illegible] meteorological satellites, considerably more surface pressure sensors in [illegible] areas, and an improvement in wind measurements in equatorial [illegible]. Presently, the density and accuracy of available data are not [illegible] with sophisticated models and also not with initialization [illegible]. This is in agreement with results summarized by Reuter [1982] at the [illegible] on Current Problems of Weather Prediction, Vienna, Austria, June [illegible]. Therefore, meteorological data management has to reconcile scientific-[illegible] considerations with cost-benefit analyses.

[illegible]

Because of the availability of new and powerful technology in the near [illegible], geodetic and meteorological data are expected to become increasingly more diversified and voluminous both regionally and globally, and its quantity and quality are subject to change. Primarily in the field of geodesy, its [illegible] will be restricted because of military considerations. Gravity [illegible] surveys are expected to have a profound effect on geodetic data [illegible]. Meteorological data generation, accuracy and density have to be [illegible] in conjunction with advanced as well as cost-effective numerical [illegible] prediction models and associated computational efforts. For the [illegible] of wind fields, diagnostic equations superior to the classical [illegible] and omega equation are available. Long range numerical weather

[illegible] for the full exploitation of available observations, for [illegible] of convection instabilities, and for correlated extension to a [illegible] a non-hydrostatic generation model with an invariant [illegible] in the (x,y,z,t)-system and an already established [illegible] for the vertical wind velocity.

[illegible]

[illegible] 1 [illegible] "[illegible] Polar Environmental Satellites Product List" [illegible] Environmental Satellite Service, Suitland, Maryland. Figure 2 is [illegible] included in the references.

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